

UNIT III

HOW TO PERFORM RCM

Module 8

ANALYTICAL METHODS

ANALYTICAL METHODS

Module Preview:

Introduction

- **Introduction**
- **Interval Calculations**
- **Cost Calculations**
- **Cautions and Warnings**
- **Spreadsheet Exercise**
- **Review and Summary**

ANALYTICAL METHODS

Module Objective:

Introduction

This module will provide information on different analytical methods that may be used in RCM analysis:

- 1. Introduce some methods of determining task intervals**
- 2. Demonstrate the cost equations used by the IRCMS software**
- 3. Discuss limitations and cautions associated with these methods**

ANALYTICAL METHODS

On-condition Task:

Interval Calculations

- Inspection interval (I) (Ref: NAVAIR 00-25-403):

$$I = PF/n$$

Where:

PF = interval from potential failure to functional failure

n = number of inspections during PF interval

Where:

- Using Pacc (safety or non-safety)

$$n = \ln(Pacc) / \ln(1-\theta)$$

- Using Cost optimization (non-safety)

$$n = \frac{\ln [(-MTBF \cdot C_i / PF) / ((C_{npm} - C_{pf}) \cdot \ln(1-\theta))]}{\ln(1-\theta)}$$

ANALYTICAL METHODS

On-condition Task:

Interval Calculations

Derivation: $n = \ln(P_{acc}) / \ln(1 - \theta)$

Theta = probability of detecting a Potential Failure in one inspection assuming it exists

(1-theta) = probability of not detecting a Potential Failure in one inspection assuming it exists

(1-theta)ⁿ = probability of not detecting a Potential Failure in “n” inspections assuming it exists

- Goal of inspection is $(1 - \theta)^n < P_{acc}$
- Longest inspection meeting this criteria would occur at $(1 - \theta)^n = P_{acc}$
- Solving for n:

$$n = \ln(P_{acc}) / \ln(1 - \theta)$$

ANALYTICAL METHODS

On-condition Task:

Interval Calculations

- If an inspection may require deferral of the corrective action when found the inspection interval should allow for the deferral time (T_c)
 - Applicable in continuously operating equipment or processes or where repair deferred and use continues
 - Mathematically:

$$I = (PF/n) - T_c$$

where:

T_c = Time needed to perform corrective action

ANALYTICAL METHODS

***On-condition
Task:***

Interval Calculations

LIMITATIONS

- **Method is conservative**
 - **Based on assumption that potential failure always exists**
- **If more precise interval is desired, actual failure rate and distribution needs to be considered in more detail**
 - **As more precision is pursued, loss of conservatism must be weighed against confidence in the data sources to ensure adequate levels of protection**

ANALYTICAL METHODS

On-condition Task:

Interval Calculations

$$n = \frac{\ln [(-MTBF * C_i / PF) / ((C_{npm} - C_{pf}) * \ln(1 - \theta))]}{\ln(1 - \theta)}$$

Where:

C_i = Cost of one inspection

C_{npm} = Cost of No PM

= Cost of Corrective Maint + Cost Lost Op

time

C_{pf} = Cost of repairing a PF

See NAVAIR 00-25-403

ANALYTICAL METHODS

Hard-Time Task:

Interval Calculations

- **Statistical (Weibull) or empirical (Test or sampling) methods**
- **Beyond the scope of this course**

ANALYTICAL METHODS

Failure Finding Task:

Interval Calculations

- Inspection Interval (I) (Ref: NAVAIR 00-25-403):

Determine by setting $P_{mf} = P_{acc}$

Where:

$$P_{mf} = P_{hidden} \times P_{additional}$$

P_{mf} = Probability of multiple failure occurring

P_{hidden} = Probability of the hidden failure occurring

$P_{additional}$ = Probability of an additional failure

occurring

ANALYTICAL METHODS

Failure Finding Task:

Interval Calculations

Assuming a constant failure rate for each term:

$$P = 1 - e^{-t / \text{MTBF}}$$

$$\begin{aligned} (1) \quad P_{mf} &= P_{\text{hidden}} \times P_{\text{additional}} \\ &= (1 - e^{-t / \text{MTBF}_{\text{hidden}}}) \times (1 - e^{-t / \text{MTBF}_{\text{additional}}}) \end{aligned}$$

$$(2) \quad P_{mf} = P_{\text{acc}}(t) = (1 - e^{-t / \text{MTBF}_{\text{acceptable}}})$$

ANALYTICAL METHODS

Failure Finding Task:

Interval Calculations

Combining equations (1) and (2)

$$(3) \quad (1 - e^{-t / \text{MTBF}_{\text{acceptable}}}) = (1 - e^{-t / \text{MTBF}_{\text{hidden}}}) \times (1 - e^{-t / \text{MTBF}_{\text{additional}}})$$

Two unknowns: $\text{MTBF}_{\text{acceptable}}$ and t

To determine $\text{MTBF}_{\text{acceptable}}$ solve $(1 - e^{-t / \text{MTBF}_{\text{acceptable}}})$ for a known P_{acc} and t

For example using a program established $P_{\text{acc}}(\text{at } t=1) = .000001$

Finally Equation (3) can be solved for t which is used for I
Note: equation (3) can only be solved iteratively (use the spreadsheet)

For economic/operational consequences, must be cost-effective

ANALYTICAL METHODS

Failure Finding Task:

Interval Calculations

LIMITATIONS

- Method assumes hidden and additional failures are random and independent
 - Assumption of randomness is usually conservative
 - If failures are dependent method may NOT be conservative!
- If hidden failure is not random to a high degree another task option such as Hard time may be more appropriate

ANALYTICAL METHODS

Overview:

Cost Calculations

- IRCMS Cost Analysis provides a means to compare relative cost of each task and other failure management options
 - Normalized to one unit of operating time
 - Typical Cost per Unit Op time
 - = Cost of one task / task interval
 - + Cost of repairs associated with task/period between repairs

ANALYTICAL METHODS

Service/Lube:

Cost Calculations

- **Service/Lube Task**

SL_{OP} = Service/lubrication task cost per operating time

$$SL_{OP} = C_{SL} / I_{SL}$$

Where:

C_{SL} = *Cost Of One SL Task*

= (MHs to perform task) x (cost per MH) + material cost

I_{SL} = *Task Interval*

ANALYTICAL METHODS

On-Condition:

Cost Calculations

• On-condition Task

OC_{OP} = On-condition task cost per operating time

$$OC_{OP} = ((C_{OC} / I_{OC}) * (L - (I_I - I_{OC})) / L) + C_R / MTBF$$

Where:

C_{OC} = Cost of one OC Task (Not including repair costs)
(MHs to perform task) * (cost per MH) + cost of materials

L = *Item Design Life*

I_I = *Initial Inspection Interval* (Inspection Threshold)

I_{OC} = *Task Interval*

$MTBF$ = *Mean time between failures (both potential and functional with task in place)*

C_R = *Average Repair Cost.*

Include all failures (potential and functional failures)

Include secondary damage

Include the cost of multiple failures in the functional failure portion of the cost

ANALYTICAL METHODS

Hard-Time:

Cost Calculations

- **Hard-Time Task**

HT_{OP} = Hard time task cost per operating time

$$HT_{OP} = [C_{HT} (S) + C_R (1-S)] / [(S) I_{HT} + (1-S) K I_{HT}]$$

Where:

C_{HT} = *Cost Of One HT*

= (MHs to perform task) x (cost per MH) + cost of materials

S = Percentage of items that survive to the hard time limit

I_{HT} = *Task Interval*

K = *Premature Failure Factor*

= Average age of premature failures as a percentage of I_{HT} .

(Note: $K I_{HT}$ is used to estimate MTTF of premature failures.)

C_R = *Average Repair Cost if HT not accomplished.*

Ensure secondary damage is included

For hidden functions include the cost of multiple

ANALYTICAL METHODS

Failure Finding:

Cost Calculations

- **Failure Finding**

FF_{OP} = Failure Finding task cost per operating time

$$FF_{OP} = C_{FF} / I_{FF} + C_R / MTBF$$

Where:

C_{FF} = *Cost Of One Inspection*

= (MHs to perform task) x (cost per MH) + cost of *materials*

I_{FF} = *Task Interval*

$MTBF$ = *Mean time between failures (with task in place)*

C_R = *Average Repair Cost.*

- Average cost of repairing the functional failures found by the inspection and those that become evident by multiple failures not prevented.

ANALYTICAL METHODS

Overview:

Cost Calculations

- No PM (Run to Failure)

NO_{OP} = "No PM" cost per operating time

$$NO_{OP} = C_R / MTBF$$

Where:

C_R = *Average Repair Cost*

- Average cost to repair the functional failure and secondary damage.
- For hidden functions, include the cost of multiple failures.
- Include operational impact if it has been converted to "cost".

$MTBF$ = *Mean time between failures (with no task in place)*

ANALYTICAL METHODS

Overview:

Cost Calculations

- **Other Action**

OA_{OP} = “Other action” cost per operating time

$$OA_{OP} = C_{OA} / L_R$$

Where:

C_{OA} = Total cost to develop and
implement “Other Action”

L_R = Total *remaining life of system/fleet*

ANALYTICAL METHODS

Overview:

- All methods are approximations
- Subject to changes in data
 - Consider sensitivity
 - Schedule follow-up validation of assumptions (Age Exploration)
- User is responsible for understanding the limits and applicability of each method
- Not every failure mode requires in depth analytical analysis (pick your battles)
 - Estimates can be used in many cases

Cautions and Warnings

Note: Equations discussed on the following slides describe the current methods provided in NA-00-25-403. Users should stay abreast of differences between latest NA-00-25-403 methods and those used in IRCMS

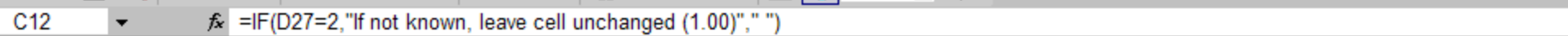
ANALYTICAL METHODS

Overview:

**Spreadsheet
Exercise**

- **Exercise**





A	B	C	G	H	I	J	K	L	M
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For proper use of this spreadsheet, refer to
NAVAIR 00-25-403 section 3.5.5 and Appendix B
section 1.2

Enter Part Name:

End Item: Program 1

PF Interval:	2500.00	Flight Hours	▼
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Severity Class: 

P_{app} 0.00000100

Is this an evident or hidden failure?

Evident

Leave cell unchanged (1.00)

1.00

Probability of detection in one inspection:	95%	
---	-----	--

Leave blank unless other than default values above:

Number of inspections required during PF Interval:	4.61	Flight Hours
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Task Interval: 542.10

RISK CATEGORY

Program 1

Program 2

I	0.0000010000	0.0000012500
II	0.0001000000	0.0000025000
III	0.0010000000	0.0000250000
IV	0.0100000000	0.0025000000

Table Values Copied from Title Page

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MEASUREMENT BASE

CONVERSION FACTORS

Days	0.7604166666	0.7604166666
Months	0.0256410300	0.0256410300
Years	0.0020833333	0.0020833333
Flight Hours	1.0000000000	1.0000000000
Flights	1.6000000000	1.6000000000
Engine Operating Hours	1.0000000000	1.0000000000
Catapults/Arrestments	0.2000000000	0.2000000000
Take-Offs	1.6000000000	1.6000000000
Landings	1.6000000000	1.6000000000

INSPECTION EFFECTIVENESS

50%

90%

f_x

Days	0.7604166666	0.8449141660
Months	0.0256410300	0.0277777800
Years	0.0020833333	0.0023148330
Flight Hours	1.0000000000	1.0000000000
Flights	1.6000000000	2.0000000000
Engine Operating Hours	2.0000000000	2.0000000000
Catapults/Arrestments	0.2000000000	0.1875000000
Take-Offs	1.6000000000	2.0000000000
Landings	1.6000000000	2.0000000000

ANALYTICAL METHODS

Review and Summary

- **Module Objective**
- **Introduction**
- **Interval Calculations**
- **Cost Calculations**
- **Cautions and Warnings**
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End of Module

up next.....

Unit IV Module 1 Packaging